Temperate climate - Innovative outputs nexus

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TEMPERATE CLIMATE - INNOVATIVE OUTPUTS *NEXUS*

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Abstract.

Technological change is a vital human activity that interacts with geographic factors and environment. The purpose of the study here is to analyse the relationship between geo-climate zones of the globe and technological outputs in order to detect favourable areas that spur higher technological change and, as a consequence, human development. The main finding is that innovative outputs are higher in geographical areas with a temperate climate (latitudes). In fact, warm temperate climates are favourable environments for human societies that, by a long-run process of adaptation and learning, create platforms of institutions and communications systems, infrastructures, legal systems, economic governance and socio-economic networks that support inventions and diffusion of innovations. The linkages between observed facts show the vital geo-climate sources of fruitful patterns of the technological innovation and economic growth.

Keywords: Innovation, Temperate Zone, Climate, Technology, Technological Change, Patent, Economic Growth, Society.

JEL classification: O10; O30; R1; R11; R12.

The problem

Climate is a major geographical factor that affects human activity and economic development (Chhetri *et al.,* 2010; 2012). However, studies of the geography of innovation show a dearth of research on the interrelationships between climate zones and technological performance (Krugman, 1991; Rosenberg, 1992; Smithers and Blay-Palmer, 2001; Howells and Bessant, 2012). Climate can be a basic factor for spurring the origin and diffusion of technological innovations, though it is a difficult assumption to test (Abler *et al.,* 2000; Ruttan, 1997; *cf.* Moseley *et al.,* 2014; Robbins *et al.,* 2014).

An interesting problem of the economics of innovation is: What are the patterns of technological innovation across different geo-climate zones of the globe? This study confronts this question by developing an empirical analysis, which endeavours to detect the fruitful relationship between innovative outputs and climate zones, which can explain path-dependence of higher technological and economic performances of some societies.

In particular, this important issue is crucial to improving our understanding of the geographical sources of technological change (Feldman and Kogler, 2010; Feldman and Florida, 1994). This study is carried out by an approach of scientific realism (Thagard, 1988, p. 145) and is a part of a large research program *à la* Lakatos (1978) that aims to detect concomitant and complex determinants of technological change.

The Backdrop of Prior Research and Conceptual Grounding

Economic growth is driven by technological innovations and some scholars explain the likely relationships between resources and development of new technology by the hypothesis of induced innovation (*cf.* Ruttan, 1997; Gitay *et al.,* 2001; Rodima-Taylor *et al.,* 2012). This hypothesis refers to the process by which societies develop technologies that facilitate the substitution of relatively abundant (hence, cheap) factors of production for relatively scarce (hence, expensive) factors in the economy (Hayami and Ruttan, 1985). In fact, Ruttan (1997, pp. 1520-2521) considers new technology as developed and adopted in response to changes in the geographical, economic and social environment (*cf.* also Goldberg, 1996).

The climate, a main geographical factor of Earth's system, affects societies and their posture towards patterns of the technological innovation (*cf.* Hayami and Ruttan, 1985, pp. 506*ff;* Neil *et al.,* 2012*;* Moseley *et al.,* 2014*;* Robbins *et al.,* 2014). Lichtenberg (1960) argues that the geographical factors rather than proximity to raw materials or markets influence production of knowledge creation. Montesquieu (1947[1748]) argued that the climate shapes human attitude, culture and knowledge. These factors tend to be localised in specific geo-economic places and support the cumulative nature and concentration of innovative activities (Feldman and Audretsch, 1999, pp. 411-412; Coccia, 2004, p. 34; Agee and Crocher, 1998; Krugman, 1991, p. 55; Crevoisier, 2004; Macdonald, 1989; McL Lamberton, 1998; Neil *et al.,* 2012). The novel scientific field of the geography of innovation analyses the location and agglomeration in geo-economic areas as key determinants of technological change, knowledge spillover and entrepreneurship (*cf.* Audretsch and Feldman, 2003; Howells and Bessant, 2012). In particular, geo-economic areas with knowledge spillovers and skilled labour generate an *accumulation force* for firms, institutions, research labs, etc. supporting further innovative activities (*cf.* Feldman, 2003, pp. 311-312). The economic history shows the concentration of innovative activities in specific places such as in Italy during the Renaissance period, England during the industrial revolution, in USA for ICTs, etc. These geo-economic areas have supported "institutional thickness" (Amin and Thrift, 1993), which provides a platform for organising people and resource to support knowledge creation, knowledge spillover and innovative outputs (*cf.* Allen, 1997; Marceau, 2000).

In fact, Feldman and Kogler (2010, p. 387) claim that:

> geography also provides a platform to organize resources and relationships for economic activities. Beyond the natural advantages of resource endowments, proximity to markets, or climate, certain places have internal dynamics that increase the productivity of investments and results in higher innovation and creativity…. These internal dynamics are so socially constructed and involve a variety of actors (*cf.* Rosenthal and Strange, 2003).

Audretsch and Feldman (1996) discuss the tendency of innovations to cluster spatially, such as in large cities, whereas industry agglomeration is due to natural advantages, resources and other factors of the physical geography (*e.g.* climate, water, etc.). These studies pave an important conceptual background for supporting the vital analysis of the vital relation between the human activity of technological change and specific geographic factors (*e.g.* the climate). The next section presents a methodology to analyse and explain the interrelationship between innovative outputs and geo-climate zones of the globe.

Study Design and Methodology

Hypothesis and Research Design

The hypothetical approach is based on the following hypothesis ($HP\phi$), which this study intends to test:

> $HP\phi$: Technological outputs are positively affected by temperate climate of the globe.

The purpose of the present study is to ascertain whether statistical evidence validates the hypothesis ($HP\phi$).

Data, sources and study design

- After a preliminary study, the sample is based on 109 countries (Appendix A).
- Data were subjected to horizontal and vertical cleaning, excluding some years with missing values and/or outliers. The normal distribution of variables is checked by Curtosi and Skewness coefficients, as well as by the normal Q-Q plot. As initial variables do not have normal distributions, a logarithmic transformation has adjusted these distributions in order to apply correctly parametric estimates.
- The indicators of this research and their sources are indicated in table 1. Time lags between variables are considered in order to analyse the logical linkages and reduce the problem of endogeneity in econometric modelling. As far as technological indicators are concerned, innova-

tions are protected by patents, which can indicate the current innovations of countries and also commercially promising inventions (*cf.* Coccia, 2010). According to Hunt and Gauthier-Loiselle (2011, p. 32): "the purpose of studying patents is to gain insight into technological progress, a driver of productivity growth, and ultimately economic growth".

Table 1 –Data and sources

Variables

- *Longitude* (GeoNames, 2014): LONG -- *Latitude* (GeoNames, 2014): LAT
- *Population growth (1990-1996)ϕ (POPGRW):* Annual population growth rate for year *t* is the exponential rate of growth of midyear population from year *t*-1 to *t*, expressed as a percentage.
- *Population total (1990-1996) ϕ (POPTOT):* Population is based on the *de facto* definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin
- *Human Development Index –HDI (2002*): it is a composite index that considers the education, life expectancy, national income of population across countries (United Nations Development Programme, UNDP 2004).
- *GDP per capita PPP current Int. $ (1994-2000) ϕ -GDPPC:* Gross domestic product per capita (GDPPC) by purchasing power parity current international. The gross domestic product (GDP)—the value of all goods and services produced minus the value of any goods or services used in their creation—is the most common metrics applied in socio-economic studies to measure the economic activity and wealth of nations.
- *Patent Applications of Residents (1995-2001) ϕ* (PAR): Patents of residents that are applications filed through the patent cooperation treaty procedure or with a national patent office for exclusive rights to an invention − a product or process that provides a new way of doing something or offers a new technical solution to a problem.
- *R&D Expenditure as % of GDP (1994-2000)ϕ -R&D:* Expenditures for R&D are current and capital expenditures on the creative and systematic activity that increase the stock of knowledge. This includes fundamental, applied research and experimental development work leading to new devices, products, or processes.
- *Researchers in RD per million people (1995-2001) ϕ RSRCH:* Researchers and technicians in R&D are people engaged in professional R&D activities who have received vocational and technical training in any branch of knowledge or technology.
- *Scientific and technical journal articles (1995-2001) ϕ STJOUR:* these articles refer to the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.
- *Population in urban agglomerations > 1 million (% of total population) 1990-1996 ϕ* (PUA): Population in urban agglomerations of more than one million is the percentage of a country's population living in metropolitan areas that in 2000 had a population of more than one million people.
- *Population in the largest city (% of urban population) (1990-1996) ϕ* (POPLAC): Population in largest city is the percentage of a country's urban population living in that country's largest metropolitan area.

Source of data: ϕ World Bank (2008).

The empirical evidence is based on two analyses:

- A preliminary statistical analysis is performed by descriptive statistics, bivariate and partial correlation for temperate and non-temperate zones of the globe.

- The main statistical analysis is based on ANOVA, other tests for comparisons of arithmetic means and decomposition of the territorial deviation. Moreover, estimated relationships by linear regression analysis provide main results to detect fruitful geographical areas for innovative outputs. SPSS Statistical Software (version 15 for Windows) was used.

In particular, ANOVA considers two main geo-climate zones: temperate climate zones and non-temperate climate zones. In some analyses, this study applies statistical analysis with three sets: Non-Temperate Climate Zone, North and South Temperate Climate Zone.

The statistical hypotheses of the ANOVA are:

H_0: average level of technological outputs in temperate latitudes = average level of technological outputs in NON-temperate latitudes

H_1: average level of technological outputs in temperate latitudes ≠ average level of technological outputs in NON-temperate latitudes

The expectation is that ANOVA rejects statistical H_0 in favour of H_1: average level of innovative outputs (measured by patents) in temperate latitudes is higher than countries located in NON-temperate latitudes.

The robustness of results is underpinned in the Levene Test of variance homogeneity, Test T of equality of mean and Test of Welch-Brown-Forsythe of robustness for equality of mean (the latter is a preferable test to *F* when it is not valid the hypothesis of equivalence of the variance).

In order to determine the geo-economic area (by geographical coordinates of the globe) that is favourable to support technological outputs, this study applies some working equations based on the following simple conceptual model:

LN Patents Applications per million people = f (Longitude)

LN Patents Applications per million people = f (Latitude)

The specification is a based on cubic models since they fit very well data scatter:

$$LN\ PAR_{i,1995-2001} = \theta + \varphi_1 LONG + \varphi_2 LONG^2 + \varphi_3 LONG^3 + u_{i,t} \qquad [1]$$

$$LN\ PAR_{\ i,1995-2001} = \alpha + \delta_1 LAT + \delta_2 LAT^2 + \ \delta_3 LAT^3 + \varepsilon_{i,t} \qquad [2]$$

The models [1] and [2] are estimated by Ordinary Least Squares method. These estimated relationships are polynomial functions continuous and infinitely differentiable. The methodology maximises these functions applying the classic mathematical optimisation methods[1] to find local optimum that indicates the fruitful geographical zone for supporting innovative activity.

In addition,

- For all 109 countries of the sample, this study has selected the top 10 cities based on their population from the geographical database GeoNames (2014) in order to have the most important and representative cities per country. This study assumes that innovations have origin in larger cities where there is accumulation of human and physical capital, universities, banks and other institutions (Dicken, 2011). After that, the methodology has associated to these cities (with their population) the geographical coordinates (longitude and latitude), respectively, in order to compute the innovative centre of gravity of the country: arithmetic mean of the geographical coordinate (longitude x_i and latitude y_i) [2] of cities weighted with their populations n_i (Girone and Salvemini, 1999). The formula is:

$$\bar{x} = \frac{\sum_{i=1}^{s} x_i n_i}{\sum_{i=1}^{s} n_i} \qquad \bar{y} = \frac{\sum_{i=1}^{s} y_i n_i}{\sum_{i=1}^{s} n_i} \qquad [3]$$

  $(\bar{x}, \bar{y})$ is the geographical barycentre of the country and is a strong indicator of agglomerative forces and engines of innovative activities. The centre of gravity of the innovative activity, considering the roundness of the earth mainly for countries with wider territory, is given by[3, 4]:

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1 One of the necessary conditions for the functions of one variable in order to have the solution $x=x^*$ to be a maximum or a minimum is: $\frac{df(x)}{dx} = 0 \quad for\ x = x^*$ (1*) In this case, x is a stationary point

2 In order to indicate the latitude and longitude in decimal number, the minutes are divided by 60: *e.g.* Lat. East 7°40' is 7+40/60=7.667.

3 rad is the radian: the standard unit of angular measure. *Note*: angle in degrees=angle in radians ×(180°/π)

4 The equations provide the value in radian. To transform the values in degree° and minute', the formulas are: 1°=(π/180)rad; 1'=(π/10800)rad.

$$\bar{x}_{rad} = arc\ \mathrm{tg}\left(\frac{\sum \sin x_i \cos y_i n_i}{\sum \cos x_i \cos y_i n_i}\right) \quad [4]$$

$$\bar{y}_{rad} = arc\ \mathrm{tg}\left(\frac{\cos \bar{x} \sum \sin x_i n_i}{\sum \cos x_i \cos y_i n_i}\right) \quad [5]$$

The variability of territorial distribution is measured by the territorial dispersion that considers the roundness of the earth (*cf.* Girone and Salvemini, 1999):

$$\sigma_{(X,Y)\ rad} = ar \cos\left(\frac{\sum \cos x_i \cos y_i n_i}{N \cos \bar{x} \cos \bar{y}}\right) \quad [6]$$

This equation [6] can provide results similar to eq. [7], which is based on formulas [3]:

$$\sigma_{(x,Y)} = \sqrt{\frac{\sum_{i=1}^{s}(x_i-\bar{x})^2 \cdot n_i + \sum_{i=1}^{s}(y_i-\bar{y})^2 \cdot n_i}{N}} \quad [7]$$

The statistical analysis considers two main climate zones of the globe based on world map of the Köppen-Geiger climate classification (*see* Kottek *et al.,* 2006, p. 260*ff*). In particular, this climate classification of the earth surface in different zones can be critical to understanding variability sources of patterns of the technological innovation (*cf.* Zscheischler *et al.,* 2012). For the sake of simplicity, this study divides the world in two main zones (*cf.* Kottek *et al.,* 2006): temperate climate (*i.e.*: based on warm temperate climates and snow climates) and non-temperate climate (*i.e.*: Equatorial, Arid and Polar climates).

This study applies a decomposition of territorial dispersion considering these two main sets (*i.e.* temperate and non-temperate climate zones). The statistical units of the territorial distribution are clustered in *r* sub-sets of N_k ($k=1, 2, ..., r$) with a specific statistical feature: in this study k=2 (countries within temperate and non-temperate climate).

n_{ki} are the frequencies of the statistical units i-*th* of the sub-set k-*th* (*i.e.* patents per million people).

n_i is the frequency of the statistical units of the whole set.

If the geographical coordinates of the centre of gravity of the phenomenon of each sub-set are:

$$\bar{x}_k = \frac{\sum_{i=1}^{s} x_i n_{ki}}{\sum_{i=1}^{s} N_k} \quad [6] \qquad \bar{y}_k = \frac{\sum_{i=1}^{s} y_i n_{ki}}{\sum_{i=1}^{s} N_k} \quad k=1,2,...,r \quad [8]$$

If the centre of gravity of the phenomenon of whole set is:

$$\bar{x} = \frac{\sum_{i=1}^{s} x_i n_i}{\sum_{i=1}^{s} N} \qquad [8] \qquad \bar{y} = \frac{\sum_{i=1}^{s} y_i n_i}{\sum_{i=1}^{s} N} \qquad [9]$$

Hence, the territorial deviation is:

$$Dev(X,Y) = N\sigma_{X^2} + N\sigma_{Y^2} = \sum_{i=1}^{s}[(x_i + \bar{x})^2 + (y_i + \bar{y})^2]n_i \qquad [10]$$

Thereby, the decomposition of territorial dispersion is (X=Longitude; Y=Latitude):

$$Dev(X,Y) = \sum_{k=1}^{r}\sum_{i=1}^{s}[(x_i + \bar{x}_k)^2 + (y_i + \bar{y}_k)^2]n_{ki} + \sum_{k=1}^{r}[(\bar{x}_k + \bar{x})^2 +$$

$$yk+y2Nk \qquad [11]$$

The first sum is the sum of territorial dispersion within each sub-set; the second sum is the territorial dispersion of the centres of gravity of each sub-set from the centre of gravity of the whole set. This equation [11] assesses whether territorial distributions of each sub-set are more or less homogenous considering their centre of gravity and territorial dispersion. The specified formula for this study is:

$$Dev(X) + Dev(Y) = Dev(X_{non\,Temp}) + Dev(Y_{non\,Temp}) + Dev(X_{Temp}) +$$

$$Dev(Y_{Temp}) + (\bar{x}_{non\,Temp} - \bar{x})^2 \cdot N_{non\,Temp} + (\bar{y}_{non\,Temp} - \bar{y})^2 \cdot$$

$$N_{non\,Temp} + (\bar{x}_{Temp} - \bar{x})^2 \cdot N_{Temp} + (\bar{y}_{Temp} - \bar{y})^2 \cdot N_{Temp} \qquad [12]$$

Statistical Analysis and Evidence

Descriptive statistics show high variance of some variables (tab. 2).

Table 2. Descriptive statistics between Non-temperate and temperate zone

Variables	*NON-TEMPERATE ZONE*			*TEMPERATE ZONE*		
	N.	*Arithmetic mean*	*St. Deviation.*	*N.*	*Arithmetic mean*	*St. Deviation.*
PAR	118	23.21	198.65	397	235.81	437.76
R&D	27	0.40	0.44	147	1.35	0.91
RSRCH	32	527.89	936.36	200	2,146.92	1,356.13
STJOUR	86	22.89	71.40	273	240.68	277.38
GDPPC	118	3,843.83	3,722.53	397	12,485.98	9,982.74
HDI	118	0.65	0.16	376	0.83	0.11
POPGRW	118	2.11	0.72	397	0.64	1.25
POPTOT	118	36,104,405.93	42,879,244.66	397	58,789,104.61	189,374,848.44
POPLAC	102	30.85	16.62	296	24.78	14.28
PUA	91	21.71	19.70	280	23.31	13.07

Note: *N* indicates several cases over the period; PAR= Patent Applications Residents (1995-2001); R&D= R&D Expenditure as % of GDP (1994-2000); RSRCH= Researchers in R&D per million people (1995-2001); STJOUR= Scientific and technical journal articles (1995-2001); GDPPC= GDP per capita PPP current Int. $ (1994-2000); HDI= Human Development Index –HDI (2002); POPGRW= Population growth (1990-1996); POPTOT= Population total (1990-1996); POPLAC= Population in the largest city (% of urban population) (1990-1996); PUA= Population in urban agglomerations > 1 million (% of total population) 1990-1996.

Table 3 displays the strong positive association between Patent Applications Residents and GDP per capita; Human Development Index; Population in urban agglomerations > 1 million (% of total population) in temperate and Non-temperate zones (except between PAR and PUA in Temperate zones, where Pearson's r is lower: 0.207).

Table 3 – Bivariate correlations (Pearson's *r*)

		NON-TEMPERATE ZONE			
		PAR	*GDPPC*	*HDI*	PUA
PAR		1	0.75(**)	0.675(**)	0.727(**)
	Sig.		0	0	0
	N	118	113	118	91
GDPPC			1	0.904(**)	0.859(**)
	Sig.			0	0
	N		113	113	86
HDI				1	0.794(**)
	Sig.				0
	N			118	91
PUA					1
	Sig.				
	N				91
		TEMPERATE ZONE			
		PAR	*GDPPC*	*HDI*	PUA
PAR		1	0.611(**)	0.674(**)	0.207(**)
	Sig.		0	0	0
	N	397	380	376	280
GDPPC			1	0.781(**)	0.338(**)
	Sig.			0	0
	N		380	366	272
HDI				1	0.291(**)
	Sig.				0
	N			376	271
PUA					1
	Sig.				
	N				280

Note: Variables in logarithmic values; **Correlation is significant at 0.01; PAR= Patent Applications Residents (1995-2001); GDPPC= GDP per capita PPP current Int. $ (1994-2000); HDI= Human Development Index –HDI (2002); PUA= Population in urban agglomerations > 1 million (% of total population) 1990-1996.

Table 4 – ANOVA and test of comparison of arithmetic mean between Temperate and NON-Temperate Zone

Variable: Arithmetic mean of *LN Patent 1995-2001 per million people*					
	ANOVA	Levene Test Variance homogeneity	Test for independent samples. Test *T* of equality of mean		Test of robustness for equality of mean
			Equal Variances	Not equal Variances	Welch and Brown-Forsythe*
F	350.972	1.032	T=18.73	T=19.72	388.958
Sign.	(0.00)	(0.31) ψ	(0.00)	(0.00)	(0.00)
df	514	513	513	208.25	df_1=1 df_2=208.25

Note: * F has an asymptotic distribution; ψ=not significant

Table 4 confirms that the average LN Patent 1995-2001 per million people of countries in temperate zone is so much greater than countries in non-temperate zone that is credible the alternative statistical hypothesis: temperate climate are positively associated to higher technological outputs. This is a strong evidence to validate the HPϕ stated in methodology section.

Table 5 –Arithmetic mean of Patents Application per million people per three geo-economic zones

ZONES	*N.*	*PAR* *Arithmetic mean*	*St. Deviation*
Temperate South	37	167.60	226.15
Non-Temperate	118	23.21	198.65
Temperate North	360	242.82	453.57

Note: PAR= Patent Applications Residents (1995-2001).

Table 6 – Comparison of arithmetic mean per THREE geo-economic zones

Temperate NORTH, SOUTH *vs.* NON-Temperate Zones
Variable: Arithmetic mean of
LN Patent 1995-2001 per million people

	Levene Test Variance homogeneity	Test of robustness for equality of mean: Welch*	Test of robustness for equality of mean: Brown-Forsythe*
Test	4.832	201.11	151.24
Sign.	(0.008)	(0.00)	(0.00)
df1	2	2	2
df2	512	88.05	93.88

Note: * *F* has an asymptotic distribution

Tables 5-6, based on three climate zones, confirm that the average LN *Patent* 1995-2001 per million people of countries in North and South Temperate Zone is so much greater than countries in non-temperate zone that is credible a positive effects of temperate latitudes on innovative outputs.

Table 7 – Geographic coordinate regressions (Cubic model)

Dependent variable: *LN Patent 1995-2001 per million people* (Arithmetic mean)			
Latitude		*Longitude*	
Constant	–0.6394***	Constant	3.902***
Latitude	0.0317***	*Longitude*	–0.0198***
$Latitude^2$	0.0034***	$Longitude^2$	–0.0003***
$Latitude^3$	–0.00004***	$Longitude^3$	0.000003***
F	233.05	*F*	28.237
(Sign)	(0.00)	(Sign)	(0.00)
R^2*Adj.*	0.575	R^2*Adj.*	0.137
(St. Err.)	(1.65)	*(St. Err.)*	(2.35)
N	515	*N*	515

Note: ***=Sign. $p < 0.001$

The maximum/minimum of the geographic coordinates relationships [15] and [18], estimated in table 7, is calculated to determine the geographical centre of gravity of the globe that optimally supports technological outputs (PAR= Patent Applications Residents 1995-2001).

For latitude (LAT) function[5], let:

$$LN\ PAR_{\ i,1995-2001} = -0.64 + 0.032LAT + 0.003LAT^2 - 0.00004LAT^3 + \varepsilon_{i,t} \qquad [15]$$

If y=LNPAR and h= LAT= latitude, the necessary condition to maximise Eq. [15] is:

$$\frac{dy}{dh} = 0.032 + 0.006LAT^1 - 0.00012LAT^2 = 0 \qquad [16]$$

The first derivative equal to 0 gives:

$y'(h) = 0$ $\quad h_1 = 90.88$ (MAX); $h_2 = -24.21$ (MIN) [17]

these are the decimal latitudes of the globe that tend to maximise (*minimise*) the throughput of technological outputs.

For longitude (LONG) function, let:

$$LN\ PAR_{\ i,1995-2001} = 3.902 - 0.019LONG - 0.0003LONG^2 + 0.000003LONG^3 + u_{i,t} \quad [18]$$

[5] Note that $\varepsilon_{i,t}$ is the error term.

If y=LNPAR and k= $LONG$= Longitude, the necessary condition to maximise Eq. [18] is:

$$\frac{dy}{dk} = -0.019 - 0.0006LONG^1 + 0.000009LONG^2 = 0 \quad [19]$$

The first derivative equal to 0 gives:

$y'(k) = 0$ $\quad k_1 = 60.99$ (MAX); $k_2 = -4.33$ (MIN) [20]

These values are the decimal longitudes of the globe that tend to maximise (*minimise*) the throughput of innovative outputs.

In short, the latitude and longitude that are favourable (*adverse*) to innovative outputs are in table 8 and represented in the globe of Figure 1.

Table 8 – Geographic coordinates of the globe favourable (adverse) to innovative outputs

Geographical coordinate	*MAX PAR*(1) Favourable are to innovative output*	*Min PAR(1) Adverse area to innovative output*
Latitude	90° 52’	–24° 12’
Longitude	60° 59’	–4° 19’

Note: (1) PAR= Patent Applications Residents (1995-2001); * it indicates the max value.

Note: PAR= Patent Applications Residents (1995-2001); * it indicates the max value

Figure 1 –Geographical points (areas) in the globe that tend to Max/Min innovative outputs

The geographical barycentre of the globe that Maximises the innovative outputs has longitude (90° 52’) and latitude (60° 59’). These geographical coordinates are in Northern hemisphere in a climate temperate zone (it is in Russian federation at the North-East of Novosibirsk). This result shows the posture of innovative outputs to locate in temperate climate of North Hemisphere.

Instead, the geographical barycentre of the globe that minimises the innovative outputs has longitude (−24° 12') and latitude (−4° 19'). This geographical area that minimises the innovative outputs is within the Non-temperate zone (below the equator line, at east of the coast of Brazil). This result means that innovative outputs are lower in non-temperate climate of the South-hemisphere of the globe.

Table 9 confirms that higher innovative outputs (first column) have a northern production in temperate climate, with lower territorial dispersion, in comparison to non-temperate zones.

Table 9 – Barycentre of geo-economic zone according to innovative output

Variable: LN *Patent Applications Residents (1995-2001)*

Geo-economic zones	Average LNPAR (St. Dev.)	Barycentre		Territorial Dispersion $\sigma_{(x,Y)}$
		Average Longitude	Average Latitude	
Temperate Zone	4.06 (1.99)	28° 28′	41° 25′	56° 22′
Non-Temperate Zone	0.22 (1.81)	−53° 2′	14° 25′	127° 53′
TOTAL	3.18 (2.53)	27° 10′	40° 59′	59° 12′

Decomposition of the territorial dispersion of Patent Applications Residents (PAR) is given by:

$$Dev(X,Y) = \sum_{k=1}^{r}\sum_{i=1}^{s}[(x_i + \bar{x}_k)^2 + (y_i + \bar{y}_k)^2]n_{ki} + \sum_{k=1}^{r}[(\bar{x}_k + \bar{x})^2 + (\bar{y}_k + \bar{y})^2]N_k$$

Table 10 – Decomposition of the deviation and territorial deviation

$\boldsymbol{Dev(X,Y)}$		**Within**		**Between**
1. Decomposition of the TERRITORIAL deviation		TEMPERATE	NON-TEMPERATE	
Value	5,737,078=	(5,117,452.52+	429,209.03)+	190,416.34
%	100=	(89.20%+	7.48%)+	3.32%
2. Decomposition of the total deviation		TEMPERATE	NON-TEMPERATE	
Value*	3,292.69=	(1,571.13+	383.97)+	1,337.59
%	100=	(47.72%+	11.66%)+	40.62%
Arithmetic* Mean	3.18	4.06	0.22	
St. Dev.*	2.53	1.99	1.81	

Note=*Logarithmic value

Territorial deviation is mainly due to territorial dispersion within the groups (Table 10), however the divergence of barycentre between non-temperate and temperate zones plays a vital role to explain the average difference between innovative outputs (last column, tab. 10). The normal decomposition of total deviation (2nd row) shows that an important source of variability is *between* groups of temperate and Non-temperate climates (40.62%), confirming that the high technological outputs are positively affected by geo-economic areas with tepid climate. This result further validates the HPϕ.

Main general remarks on empirical analyses

The statistical analysis shows, *ceteris paribus*, that in *average* innovative outputs tend to be associated to temperate climate zones where there are favourable factors of physical and human geography. In short, technological change is mainly a human activity, which locates, aggregates and develops in tepid latitudes. However, the relation between climate latitudes and technological outputs is also affected by other hidden factors (Coccia, 2012; 2011: 2014). For instance, Spain and the UK are in the same geo-climatic zone, but Spain has an annual average of about 57 patents per million people, whereas the UK has an annual average of roughly 334 patents (*cf.* Coccia, 2014).

Institutions, democratisation, cultural factors and other socio-economic factors differ across countries and tend to generate, *ceteris paribus*, a great variety of economic and technological performances, respectively, across countries within the same geo-economic zones.

Explanation of the *nexus* temperate climate-innovative outputs

The statistical evidence seems in general to support the hypothesis stated in section methodology: higher innovative outputs can be also explained by the location of countries in temperate climate zones. This result can be due to some fruitful linkages: tepid zones attract population that tends to concentrate geographically and creates dense social networks and trustful environment (Lee and Rodríguez-Pose, 2013). Concentrations of people and social interactions, in general, can support an effective circulation and diffusion of ideas, facilitating discoveries, inventions and innovations by new combinations of ideas and technical knowledge. These linkages generate path-dependence for fruitful technological progress in some places due to main historical developmental paths (*cf.* Neil *et al.,* 2012). In addition, concentration of people in tepid latitudes leads to greater demand for goods and services, and as a consequence, to more innovation and economic growth (*demand-driven effect*).

This vital *nexus* can be schematically summarised in Figure 2.

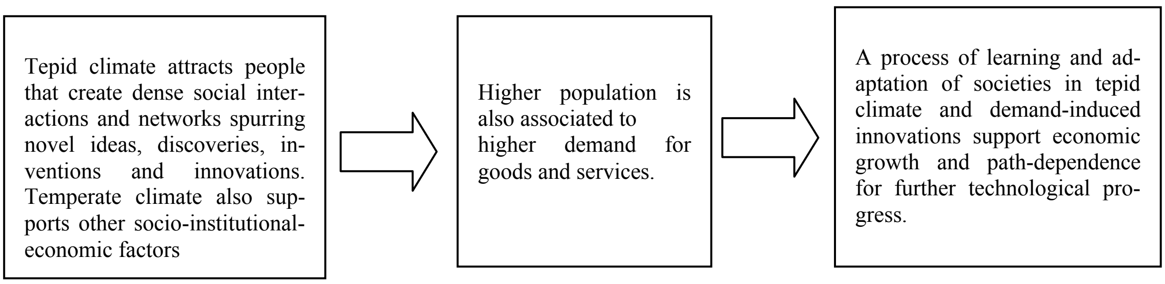

Figure 2: Fruitful linkage from temperate climate to technological and economic progress

Tepid climate zone is a main force of attraction for human population that triggers some socio-economic mechanisms for fruitful patterns of technological change also supported by geo-economic resources. In fact, Kuznets (1960, p. 328) states: "Population growth produces an absolutely larger number of geniuses, talented men, and generally gifted contributors to new knowledge whose native ability would be permitted to mature to effective levels when they join the labor force". As quoted by Strulik (2005, p. 130), Jones Charles I. writes: "More people means more Isaac Newtons and therefore more ideas". Moreover, Kremer (1993, pp. 684-685) notices that: "among technologically separate societies, those with higher population had faster growth rates of technology and population" (*cf.* Coccia, 2014). In addition, tepid climate can support the transmission of knowledge by face-to-face interactions, high intensive contacts, sharing common attitudes/interests towards specific knowledge and technology (Feldman and Romanelli, 2006; *cf.* Allen, 1997; Marceau, 2000; Von Hippel, 1994).

Aharonson *et al.* (2007, p. 92) argue that[6]:

> When people with common technical interests concentrate geographically, dense local social and professional networks emerge as their close proximity leads them to encounter one another more frequently, both by chance and through local institutions, and to develop ties that are more likely to endure than more costly to- maintain distant ties. By facilitating repeated interactions and development of overlapping social and professional connections, local concentrations of people engaged in similar technical activities create an environment facilitating trust building and rapid and effective diffusion of ideas … Through these networks flows information about promising new technical developments and important unsolved puzzles that can stimulate innovation by facilitating novel combinations of ideas and technologies and identifying emerging market opportunities. . . . Technological proximity also matters. The cumulativeness of technological advances and specificity of knowledge bases to particular technical areas and market applications makes the value of potential spillovers greater within rather than across specialized technological applications.

As a matter of fact, apt physical and human geography in tepid climate can support the establishment of fruitful platforms and infrastructures for innovative outputs that support path-dependence pathways of certain places (*cf.* Neil *et al.,* 2012). In brief, technological change is a human activity that is associated to temperate zones. Technological innovation, *de facto,* is a strategy by which societies respond and/or adapt to resource endowments, environmental, climate and socio-economic changes (*cf.* Chhetri et al., 2012; *see* Singer *et al.,* 1961). In particular, technological change is a human activity of learning and adaptation to take advantage of important territorial opportunities and/or to cope with consequential environmental and climate threats. Figure 3 shows the linkages, which can contribute to enhance the understanding of the interaction between climate as geographical factor and patterns of the technological innovation.

[6] *cf.* Gersbach and Schmutzler, 1999; Binz *et al.*, 2014; Strand and Leydesdorff, 2013.

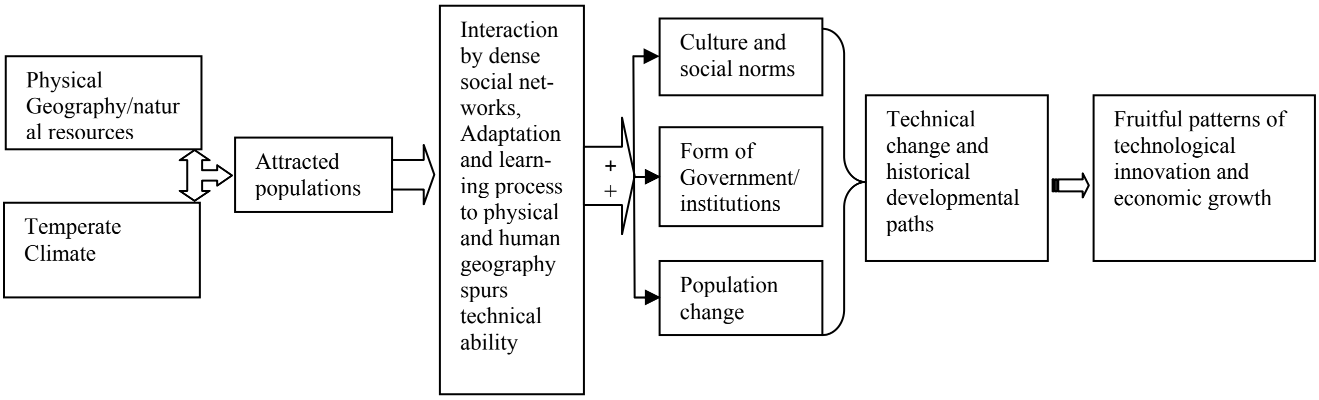

Figure 3: Linkage from temperate climate and fruitful physical geographic factors to technological and economic progress (+ : fruitful linkages)

Figures 4-5 confirms that at the origins some innovations of Mousterian industry and objects obtained with blade and small chisel in upper Palaeolithic period-for the survival and livelihood of human are mainly in tepid climate zone above the Tropic of Cancer.

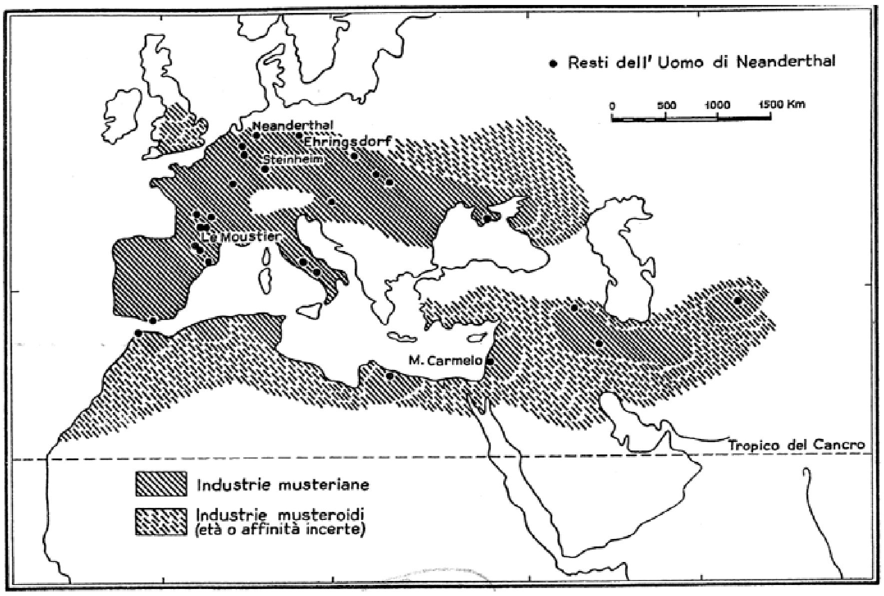

Figure 4 – Distribution of Mousterian industry (flint tools associated primarily with Homo Neanderthalensis, see dense network) mainly in temperate climate zone above the tropic of Cancer. *Source*: Singer C., Holmyard E. J., Hall A. R (1961) (eds.) *A history of technology*, Clarendon Press, Oxford, vol. 1.

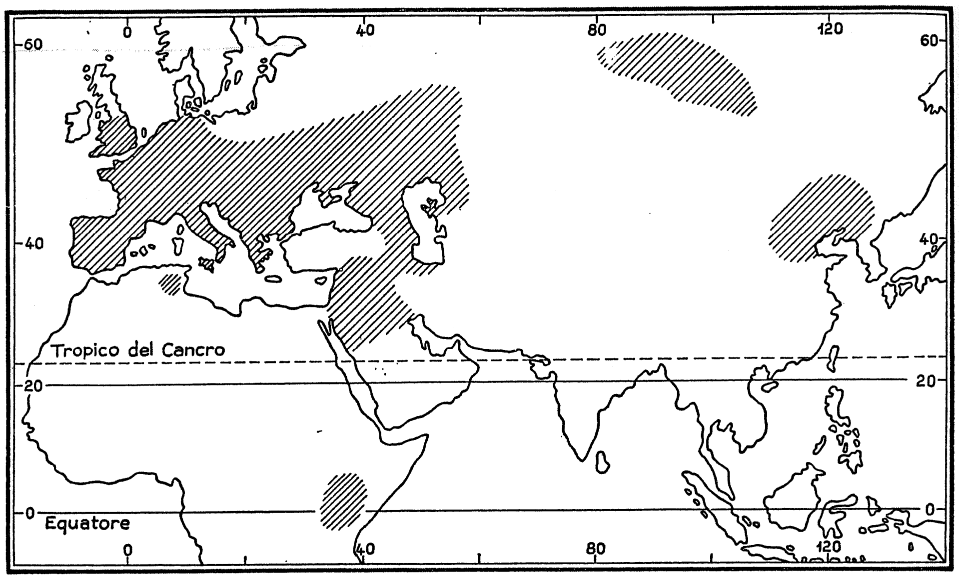

Figure 5 – Distribution of objects obtained with blade and small chisel during Upper Palaeolithic period-about 150,000 years ago. The area of these objects is mainly in temperate climate zone above the tropic of Cancer. *Source*: Singer C., Holmyard E. J., Hall A. R (1961) (eds.) *A history of technology*, Clarendon Press, Oxford, vol. 1.

Tepid climate has a vital role to create fruitful geo-economic factors, such as institutions and social networks, for supporting vibrant entrepreneurial settings and outpouring scientific opportunities, discoveries, inventions and diffusion of innovations (*cf.* Breschi and Lissoni, 2009). In particular, geo-economic space and temperate climate, associated to other apt physical (*e.g.* resources) and socio-cultural factors, can pave a specific environment to support fruitful technical knowledge atmosphere, *strictly context dependent in this space (territory) and time span.* These basic and initial conditions of geo-economic areas induce historical development pathways and path-dependence of certain places.

This study seems to show that specific tepid geo-economic areas tend to support higher innovative outputs. These are the pre-existing conditions for a profitable technological change, which is an activity of learning and adaptation by organised societies to take advantage of important territorial opportunities, to respond to scarce resources and/or to cope with consequential environmental threats (*cf.* Rodima-Taylor *et al.,* 2009; Olwig, 2012). Of course, temperate climate, is a necessary but not sufficient condition for supporting technological innovations. Temperate climate has to be associated, over time, to other driving forces in order to support long-run patterns of technological innovations (*cf.* Coccia, 2009; 2009a; 2010; 2011; 2012, 2013; 2014; 2014a).

Technological change is a human activity
of learning and adaptation by organized societies
to take advantage of important territorial opportunities,
of better chances for survival and livelihood and
to cope with consequential environmental threats and scarce resources.

Concluding Observations

Climate is a main geographical factor and pre-existing condition for technological change. In particular, investments in human and physical capital tend to be affected by climate conditions (Abler *et al.,* 2000). Tepid climate and territories create main stimuli for social, technological and economic change (Hayami & Ruttan, 1985; *cf.* Rosenberg, 1992; Smithers and Blay-Palmer, 2001). In fact, the progress of societies in tepid areas has generated main innovations to reduce the influence and dependence from scarce resources and natural environment (Hayami and Ruttan, 1985).

The study here shows higher technological outputs in temperate geo-economic areas of the globe. These results may be due to the congruence of geographical, social, political and economic factors since Palaeolithic period (Di Giano and Racelis, 2012; *cf.* Martin and Sunley, 1998). The tepid zones have created fruitful conditions for supporting the resilience (ability to adapt) of population by technological innovations. Rodima-Taylor *et al.* (2012, p. 107) claim that: "Innovations are human adaptations to changing needs and socio-economic conditions, and are therefore embedded in social processes". Moreover, climate affects cultural traits of society that by a process of learning pro-actively react and self-adapt to environmental conditions and resource endowments to survive and support technological and socio-economic progress (*cf.* Chhetri *et al.,* 2012). Hence, technological change is a strategy of learning and adaptation in natural and geo-economic systems in response to actual and/or expected environmental stimuli or their effects, in order to reduce risks and/or exploits beneficial opportunities. This study considers *technological change as a human activity of learning and adaptation by organised societies, fruitful associated to tepid zone, to take ad-*

vantage of important territorial opportunities and of better chances for survival and livelihood and/or to cope with consequential environmental threats and scarce resources.

However, climate represents a main pre-existing and basic condition for fruitful patterns of technological innovation, which are subjected to a variety of determinants during the historical development paths of societies (*cf.* Smithers and Blay-Palmer, 2001). It seems that climate and other physical geographic factors spur technological pathways and support the fortune of certain places.

This study has tried to provide, through empirical evidence, a *verisimilitude* or degree of closeness to true facts. Of course, the results of this study are explorative and not conclusive, because the main role of climate on technological change deserves to be delved more deeply into scientific analyses based also on social, psychological and anthropologic factors of human societies. These and other related issues remain the purpose of future research. The partial analysis discussed here, focusing on some critical linkages, provides interesting findings, though we know that other things are often not equal in geo-economic systems and no empirical evidence will be true in all situations. As Wright (1997, p. 1562) properly says: "In the world of technological change, bounded rationality is the rule".

Appendix A

Countries of the sample:

Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belgium, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Ecuador, Egypt Arab Rep., Estonia, Ethiopia, Finland, France, Gambia, Georgia, Germany, Ghana, Greece, Guatemala, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran Islamic Rep., Iraq, Ireland, Israel, Italy, Japan, Kazakhstan, Kenya, Korea, Rep. Kyrgyz, Latvia, Lesotho, Libya, Lithuania, Luxembourg, Macedonia-FYR, Madagascar, Malawi, Malaysia, Malta, Mauritius, Mexico, Moldova, Monaco, Mongolia, Morocco, The Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Serbia and Montenegro, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Zambia, Zimbabwe.

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